

# Measurements of $K^\pm$ , $K_s^0$ , $\Lambda$ and $\bar{\Lambda}$ and Bose-Einstein Correlations between Kaons at ZEUS

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## Abstract

Measurements of production of the neutral and charged strange hadrons in  $e^\pm p$  collisions with the ZEUS detector are presented. The data on differential cross sections, baryon-to-meson ratios, baryon-antibaryon asymmetry and Bose-Einstein correlations in deep inelastic scattering and photoproduction are summarized [1].

## 1 Introduction

After pions, strange hadrons are the most copiously produced particles in  $e^\pm p$  collisions with a centre-of-mass energy of 318 GeV at HERA. In phenomenological models based on the Lund string scheme [2], an intensity of strange quark production is regulated by a free parameter  $\lambda_s$ , which has a value in the range from 0.2 to 0.4 for different processes.

The experimental results on  $K^\pm$ ,  $K_s^0$ ,  $\Lambda$ , and  $\bar{\Lambda}$  production [3, 4] presented in this note are based on a data sample of  $121 \text{ pb}^{-1}$  collected by the ZEUS experiment at HERA. This is about 100 times larger data sample than used in previous HERA publications [5, 6] and extend the kinematical region of the measurements, thereby providing a tighter constraint on models.

## 2 Measurements of $K_s^0$ , $\Lambda$ and $\bar{\Lambda}$

Weak decaying neutral  $K_s^0$  and  $\Lambda$  are well reconstructed in the modes  $K_s^0 \rightarrow \pi^+\pi^-$ ,  $\Lambda \rightarrow p\pi^-$ ,  $\bar{\Lambda} \rightarrow \bar{p}\pi^+$  via displaced secondary vertices. The measurements have been performed in three different regions of  $Q^2$ : deep inelastic scattering (DIS) with  $Q^2 > 25 \text{ GeV}^2$ ; DIS with  $5 < Q^2 < 25 \text{ GeV}^2$ ; and photoproduction (PHP),  $Q^2 \simeq 0 \text{ GeV}^2$ . In the PHP sample, two jets, each of at least 5 GeV transverse energy, were required.

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## 2.1 Spectra of $K_s^0$ and $\Lambda + \bar{\Lambda}$ in DIS

Measured differential cross sections are shown in Fig. 1. The cross sections are compared to the absolute predictions of ARIADNE 4.12 [7] and LEPTO 6.5 [8] MC calculations. The ARIADNE program with  $\lambda_s = 0.3$  describes the  $\Lambda + \bar{\Lambda}$  data reasonably well in both  $Q^2$  samples. The description of the  $K_s^0$  data by ARIADNE is less satisfactory. The slope of the  $P_T^{LAB}$  dependence is incorrect and in the high- $Q^2$  domain the data requires  $\lambda_s < 0.3$ . The cross section at low  $x_{Bj}$  (not shown) is underestimated for both the low- and the high- $Q^2$  samples [3]. The LEPTO MC does not describe the data well and predicts a too fast grow of the cross sections with  $Q^2$ . We conclude, that for the production of baryons the data requires  $\lambda_s$  to be approximately constant, but in case of  $K_s^0$  production  $\lambda_s$  has to decrease with  $Q^2$ .

## 2.2 Baryon-antibaryon asymmetry in DIS and PHP

A positive asymmetry of 3.5% is predicted in DIS [9], due to the so-called gluon-junction mechanism that makes it possible for the *baryon number to travel* several units of rapidity, in this case from the proton beam direction to the rapidity around 0 in the laboratory frame.

The baryon-antibaryon asymmetry

$$\mathcal{A} = \frac{N(\Lambda) - N(\bar{\Lambda})}{N(\Lambda) + N(\bar{\Lambda})}$$

has been measured and compared to MC predictions from ARIADNE, LEPTO and PYTHIA [10]. The following value was obtained at high  $Q^2$  :  $\mathcal{A} = 0.3 \pm 1.3_{-0.8}^{+0.5}\%$  which has to be compared to the ARIADNE ( $\lambda_s = 0.3$ ) prediction of  $0.4 \pm 0.2\%$ . In PHP,  $\mathcal{A} = -0.07 \pm 0.6_{-1.0}^{+1.0}\%$ , compared to the PYTHIA prediction of  $0.6 \pm 0.1\%$ .

Figure 2 shows  $\mathcal{A}$  at high- $Q^2$  and in PHP. In all cases,  $\langle \mathcal{A} \rangle$  is consistent both with no asymmetry and with a very small asymmetry predicted by the Monte Carlo. However, as shown in Figs 2, in DIS the baryon-antibaryon asymmetry becomes positive and increases in the incoming proton hemisphere ( $\eta^{LAB} > 0$ ), as well as at  $P_T^{LAB}$  below 1 GeV.

## 2.3 Baryon-to-meson ratio in photoproduction

The relative yield of strange baryons and mesons was studied with the ratio

$$\mathcal{R} = \frac{N(\Lambda) + N(\bar{\Lambda})}{N(K_s^0)}.$$

Figure 3 shows  $\mathcal{R}$  for the PHP sample. For the direct-enriched sample, where  $x_\gamma^{OBS} > 0.75$ ,  $\mathcal{R}$  is about 0.4, the same value as in DIS at low  $x_{Bj}$  and low  $Q^2$  [3]. However,  $\mathcal{R}$  rises to a value of about 0.7 towards low  $x_\gamma^{OBS}$  (resolved-enriched sample), while it stays flat in the PYTHIA prediction.

In order to study this effect further, the PHP events were divided into two samples. In the first, called *fireball-enriched*, the jet with the highest transverse energy was required to contribute at most 30% to the total hadronic transverse energy. The other sample, containing all the other events, was called *fireball-depleted*. The measured  $\mathcal{R}$  (see Fig. 3, Bottom) is larger for the fireball-enriched sample, most significantly at high  $P_T^{LAB}$ , than it is for the fireball-depleted sample. This feature is not reproduced by PYTHIA, which predicts almost the same  $\mathcal{R}$  for both samples. The PYTHIA prediction reasonably describes the measured values of  $\mathcal{R}$  for the fireball-depleted sample. This is not surprising

as PYTHIA generates jets in events according to the multiple interaction mechanism, which makes several independent jets, like those in DIS or  $e^+e^-$  where baryons and mesons are created locally.

We note that the increase of the ratio  $\mathcal{R}$  toward the proton hemisphere, reflects a rapid growth of the  $\Lambda + \bar{\Lambda}$  cross section as  $\eta^{LAB}$  increases, as compared to the  $K_s^0$  cross section grow [3].

### 3 Bose-Einstein correlations of charged and neutral kaons in DIS

Primordial quantum correlations between identical bosons, so-called Bose-Einstein correlations (BEC), so far is the only method to estimate the space-time geometry of an elementary particle emission source. The measurements of the radius of the emission source have been mostly performed with pure quantum states  $\pi^\pm$ ,  $K^\pm$ ,  $p/\bar{p}$ . For mixed quantum states, like  $K_s^0$ , the information is scarce.

The results presented below were obtained with charged kaons selected using the energy-loss measurements,  $dE/dx$ . The identification of  $K^\pm$  is possible for  $p < 0.9$  GeV. The resulting data sample contained 55522  $K^\pm K^\pm$  pairs. The  $K_s^0$  mesons were identified via displaced secondary vertices. After all cuts, the selected data sample contained 18405  $K_s^0 K_s^0$  pairs and 364 triples [4].

Figure 4 shows the two-particle correlation function  $R(Q_{12})$  for identical kaons calculated using the double ratio method

$$R(Q_{12}) = \frac{R_{data}(Q_{12})}{R_{MC}(Q_{12})},$$

where  $R_{data}(Q_{12})$  is the ratio of the two-particle densities constructed from pairs of kaons coming from the same and different events.  $R_{MC}(Q_{12})$  is obtained in a similar way for ARIADNE MC events without BEC.  $Q_{12}$  is given by  $Q_{12} = \sqrt{-(p_1 - p_2)^2}$ . Assuming a Gaussian shape of emission source,  $R(Q_{12})$  were fitted by the standard Goldhaber-like function

$$R(Q_{12}) = \alpha(1 + \lambda e^{-Q_{12}^2 r^2})$$

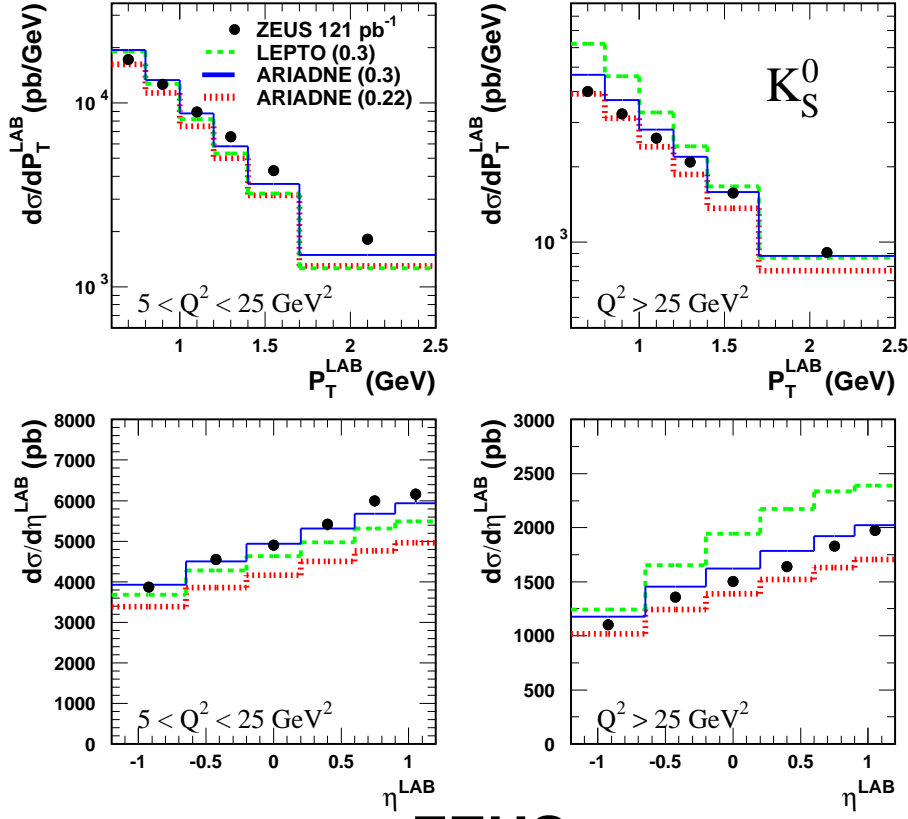
to extract the degree of the source coherence  $\lambda$  and the source radius  $r$ . The measured radii for  $K^\pm K^\pm$  and  $K_s^0 K_s^0$  are close to each other [4]. In case of  $K_s^0 K_s^0$ , the fit (see Fig. 4) does not take into account a possible contamination from the scalar  $f_0(980)$  decaying below the threshold. The most probable fraction of  $f_0(980)$  which allows to describe the excess of data over MC was estimated to be 4%. The results corrected for the  $f_0$  contamination are  $\lambda = 0.70 \pm 0.19_{-0.53}^{+0.47}$  and  $r = 0.63 \pm 0.09_{-0.08}^{+0.11}$  fm. Thus, the  $f_0(980) \rightarrow K_s^0 K_s^0$  decay can significantly affect the  $\lambda$  parameter for  $K_s^0 K_s^0$  correlations. The radius-values obtained in DIS agree with  $e^+e^-$  annihilation results at LEP [4].

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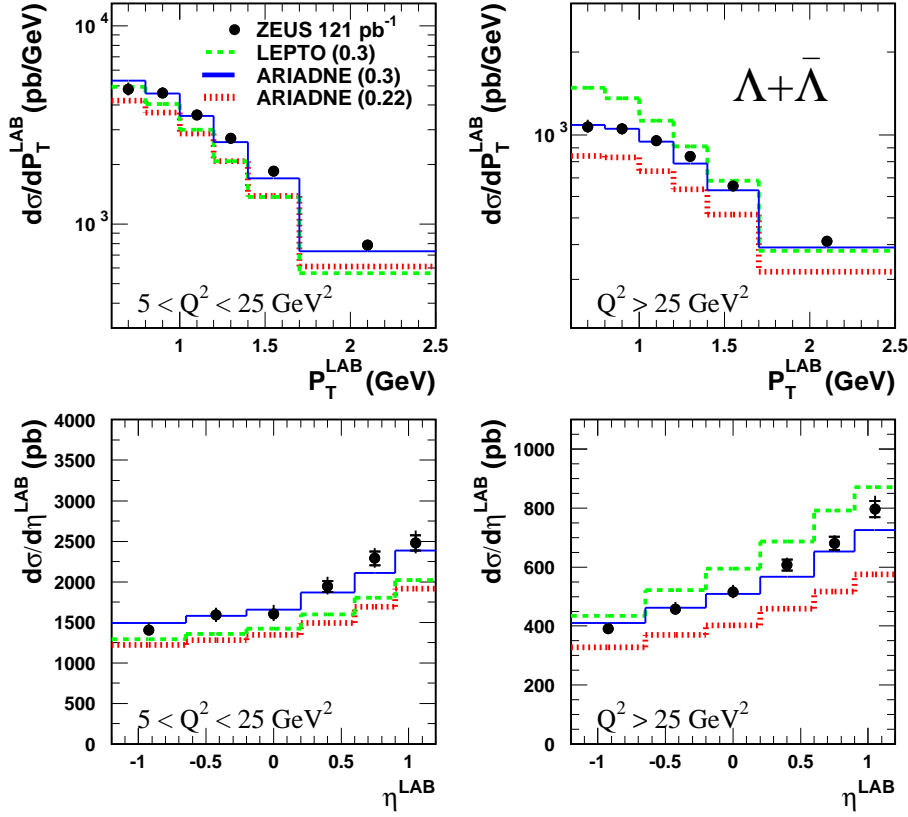
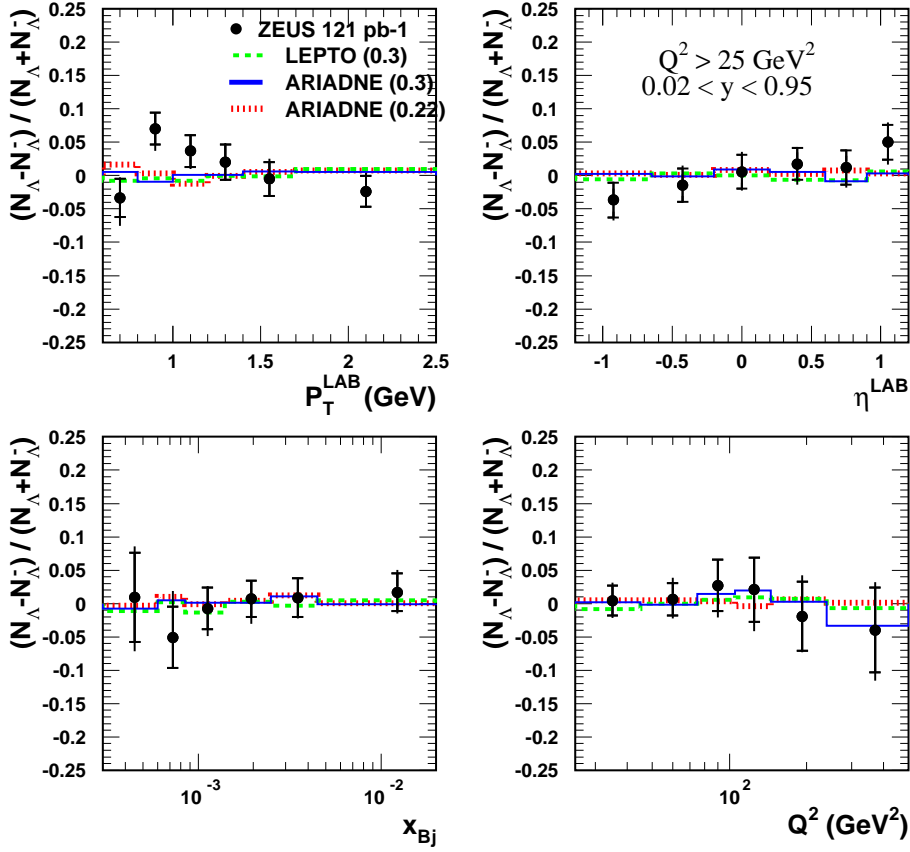


Figure 1: Differential  $K_S^0$  and  $\Lambda + \bar{\Lambda}$  production cross-sections. The model predictions are at values of a strangeness suppression factor  $\lambda_s$  shown in paranthesis.

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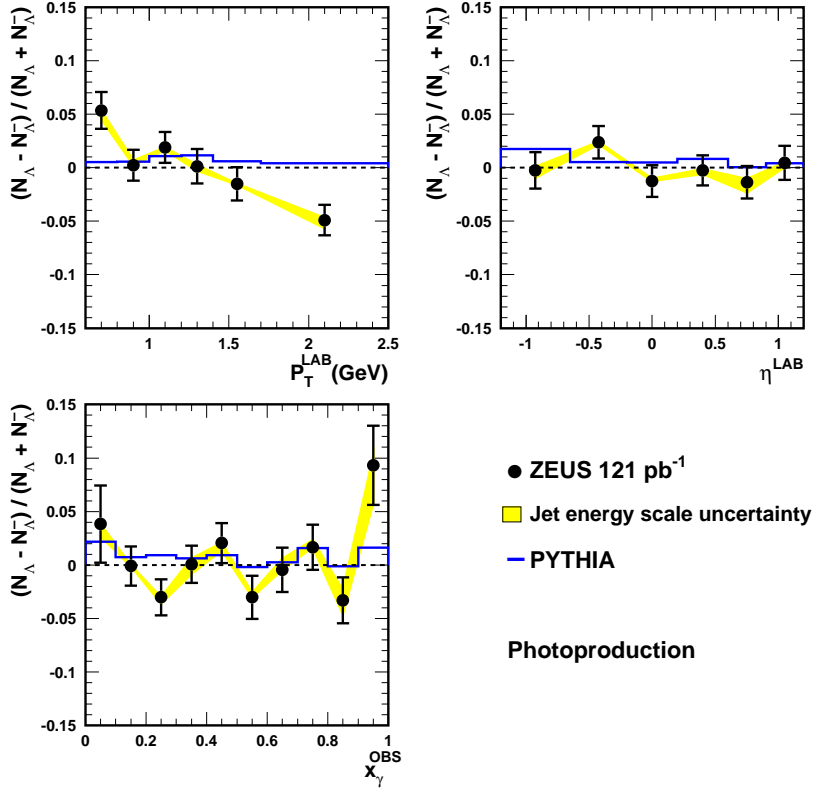
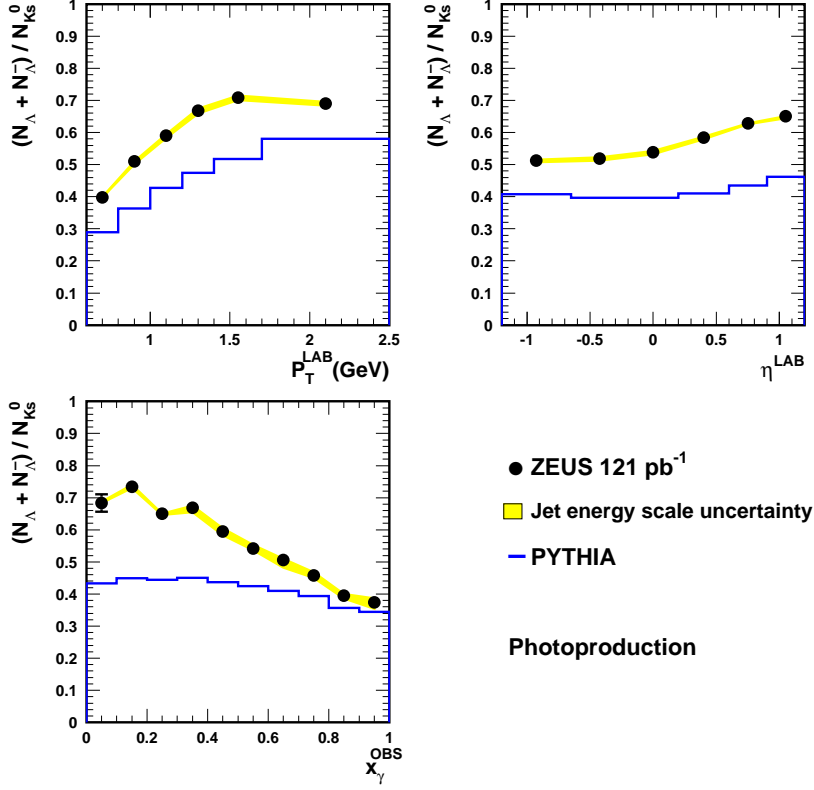


Figure 2: The baryon-antibaryon asymmetry  $\mathcal{A}$  as a function of  $P_T^{\text{LAB}}$ ,  $\eta^{\text{LAB}}$ ,  $x_{\text{Bj}}$  and  $Q^2$  for the DIS sample (top), and as a function of  $P_T^{\text{LAB}}$ ,  $\eta^{\text{LAB}}$  and  $x_{\gamma}^{\text{OBS}}$  for the photoproduction sample (bottom). The different lines are the predictions of the different MC generators, as indicated in the plots.

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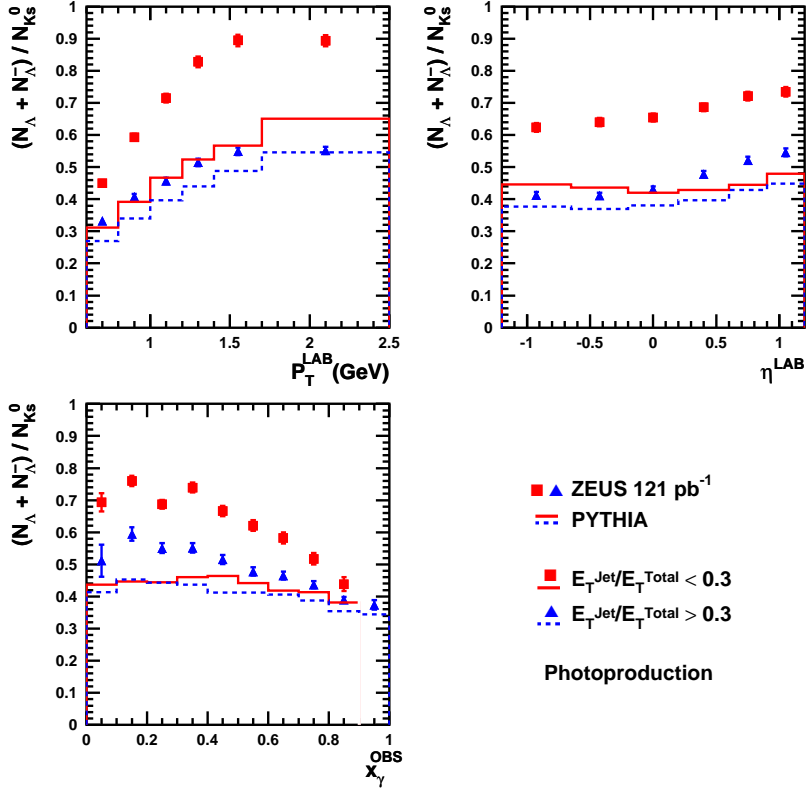


Figure 3: The ratio  $\mathcal{R}$  as a function of  $P_T^{LAB}$ ,  $\eta^{LAB}$ , and  $x_\gamma^{OBS}$  for the PHP events. Top: the ratio from the whole PHP sample. Bottom: the ratio from the fireball-enriched (squares) and the fireball-depleted (triangles) samples. The predictions from PYTHIA for  $\lambda_s = 0.3$ .

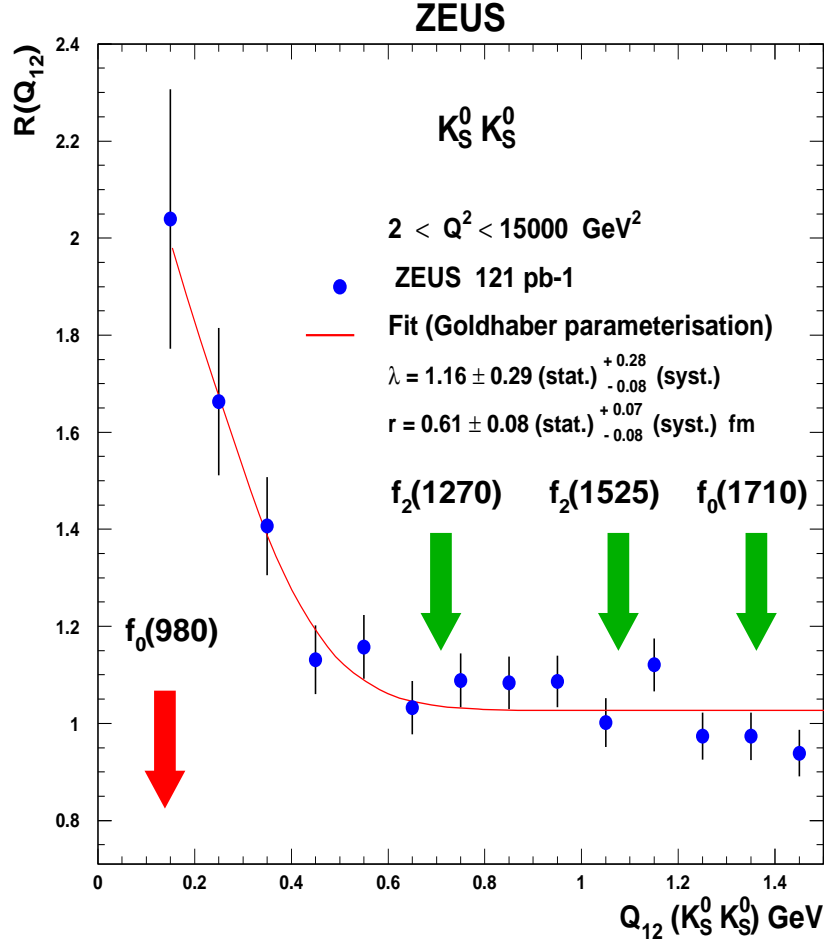


Figure 4: The two-particle correlation functions at  $\langle Q^2 \rangle = 35 \text{ GeV}^2$  for neutral kaons with fits to the Goldhaber function. Arrows indicate  $Q_{12}$  regions with contributions from resonances in the  $K_S^0 K_S^0$  system.